ELECTRICAL
& COMPUTER
ENGINEERING

ECE-595 Network Softwarization

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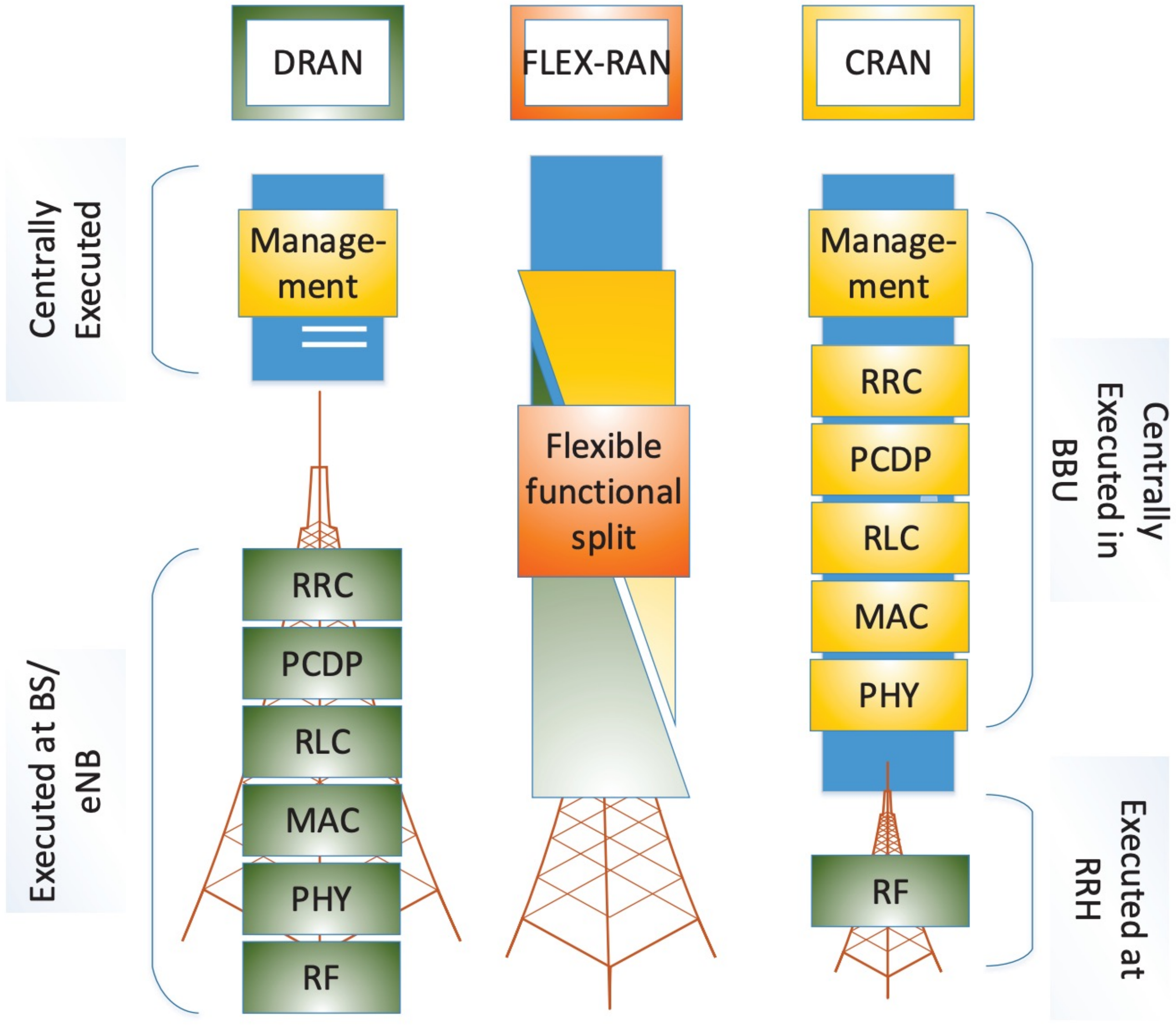
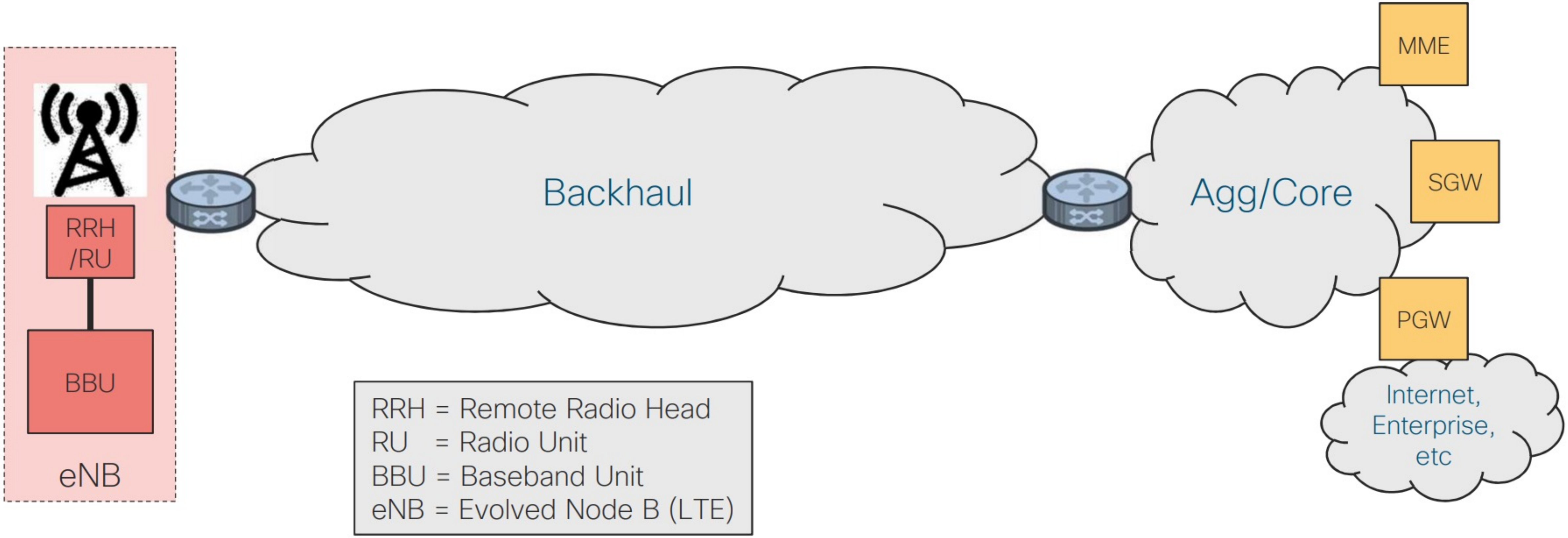
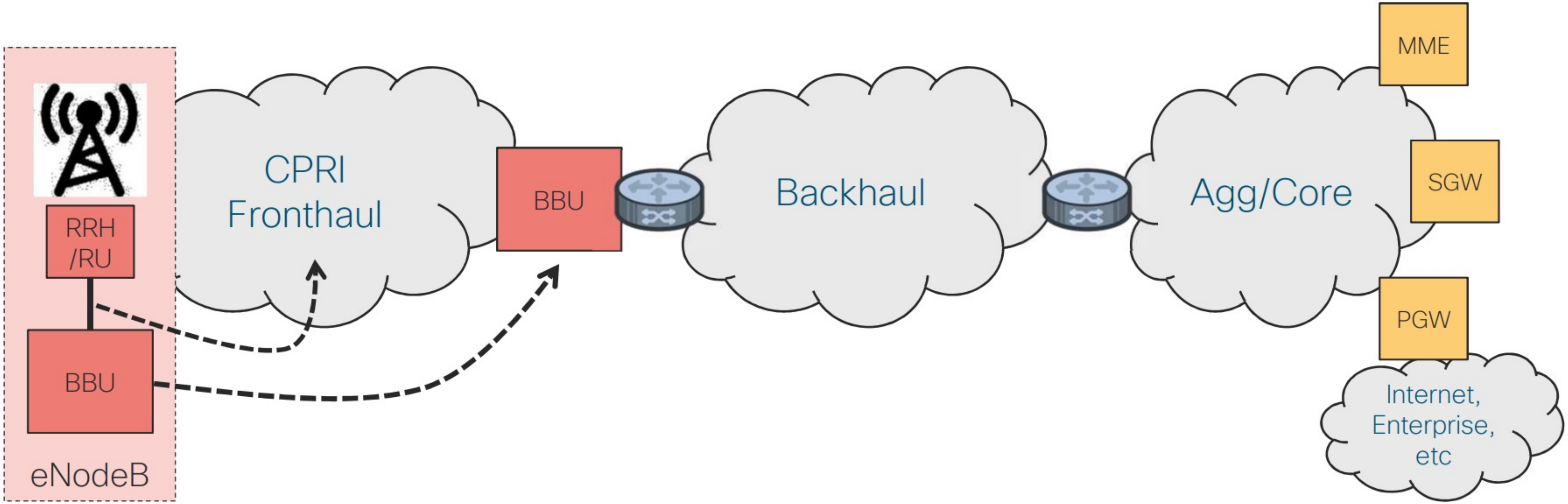
DRAN, FLEXRAN & CRAN



Traditional RAN



Transition to CRAN



Fronthauling

Transport of I/Q signals from the baseband unit to the radios is known as “Fronthaul”.

Common Public Radio Interface (CPRI) is a popular standard for transporting baseband I/Q signals to the radio unit in traditional BS.

Timing and frequency synchronization are critical elements for fronthauling.

LTE-A and LTE-A Pro systems have strict latency and delay constraints on transporting I/Q signals.

CPRI Latency Requirements

Speed of light = $2.99*10^8$ m/s. This creates a latency of 3.33 us/km.

Light travels slower in fiber due to the fiber's refractive index, so latency increases to 5us/km.

Maximum CPRI latency in LTE is 100 us.

This limits the range of fiber to about 15km-20km for LTE → range of front-haul.

CPRI Fundamentals

CPRI allows an efficient, flexible I/Q data interface for various standards such as LTE, WCDMA, GSM, etc.

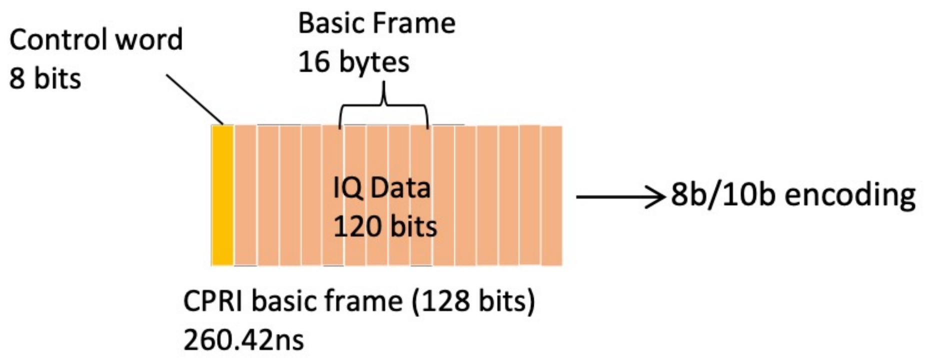
It uses one physical connection for user data, management and control signaling and synchronization.

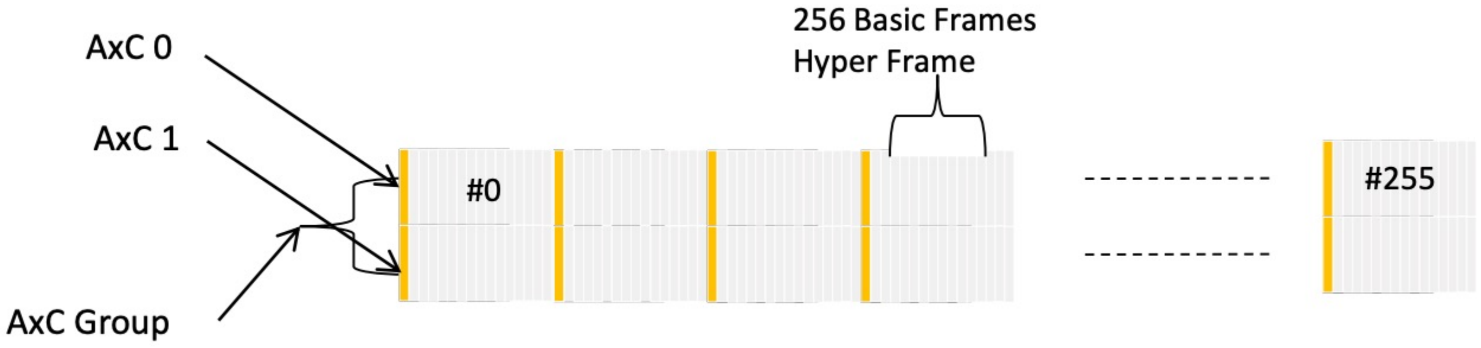
CPRI transports I and Q data of a particular antenna and a particular carrier and this “unit” is called an AxC (Antenna-Carrier) unit.

For example, in an LTE system, if I=16 bits and Q=16 bits, then one AxC is 32 bits.

Data is organized into basic frames of 16 words each. The first word of each basic frame is the control word.

Each word could be 8, 16, 32 bits, etc. The width of the word depends on the CPRI line rate.





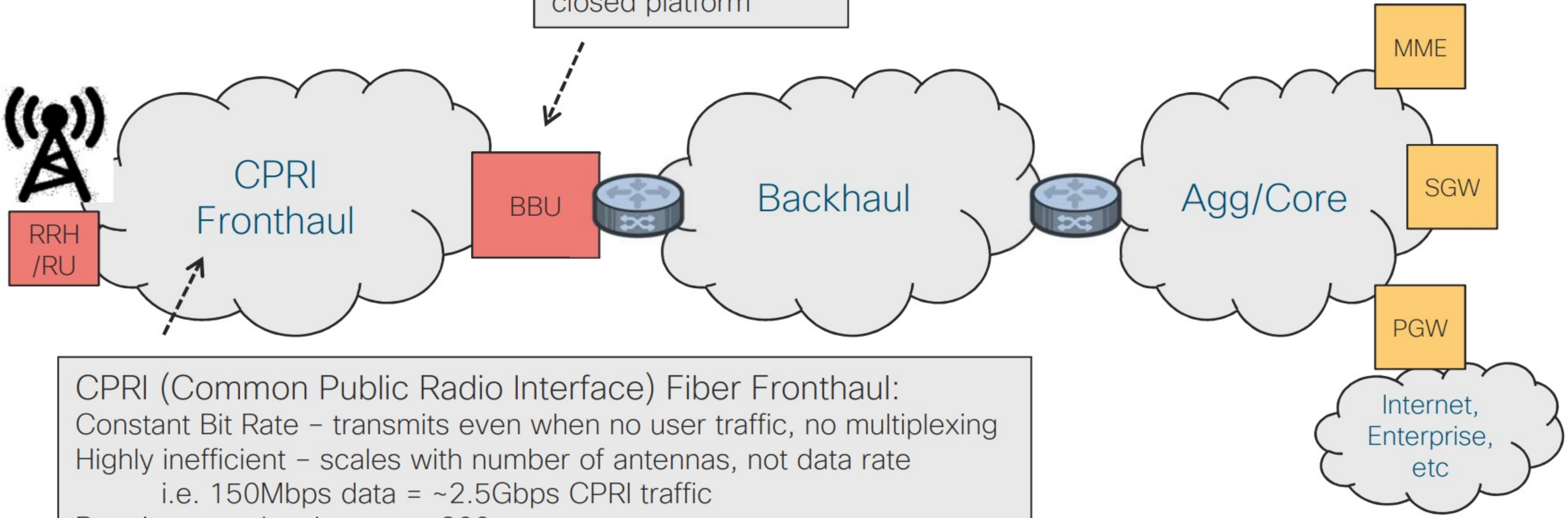
CPRI Line Rate and Transport Capacity

CPRI Rate	Line Bit Rate	Line Coding	Bits per Word	Transport Capacity (#WCDMA AxC)	Transport Capacity (#20MHz LTE AxC)
Rate 1	0.6144 Gbps	8B/10B	8	4	--
Rate 2	1.2288 Gbps	8B/10B	16	8	1
Rate 3	2.4576 Gbps	8B/10B	32	16	2
Rate 4	3.0720 Gbps	8B/10B	40	20	2
Rate 5	4.9152 Gbps	8B/10B	64	32	4
Rate 6	6.1440 Gbps	8B/10B	80	40	5
Rate 7A	8.1100 Gbps	64B/66B	128	64	8
Rate 7	9.8304 Gbps	8B/10B	128	64	8
Rate 8	10.1376 Gbps	64B/66B	160	80	10
Rate 9	12.1651 Gbps	64B/66B	192	96	12
Rate 10	24.3302 Gbps	64B/66B	384	192	24

G. Heidari, et al., «TUTORIAL: DESIGNING TO EVOLVING LTE ADVANCED PRO AND PRE–5G REQUIREMENTS,» DesignCon 2017.

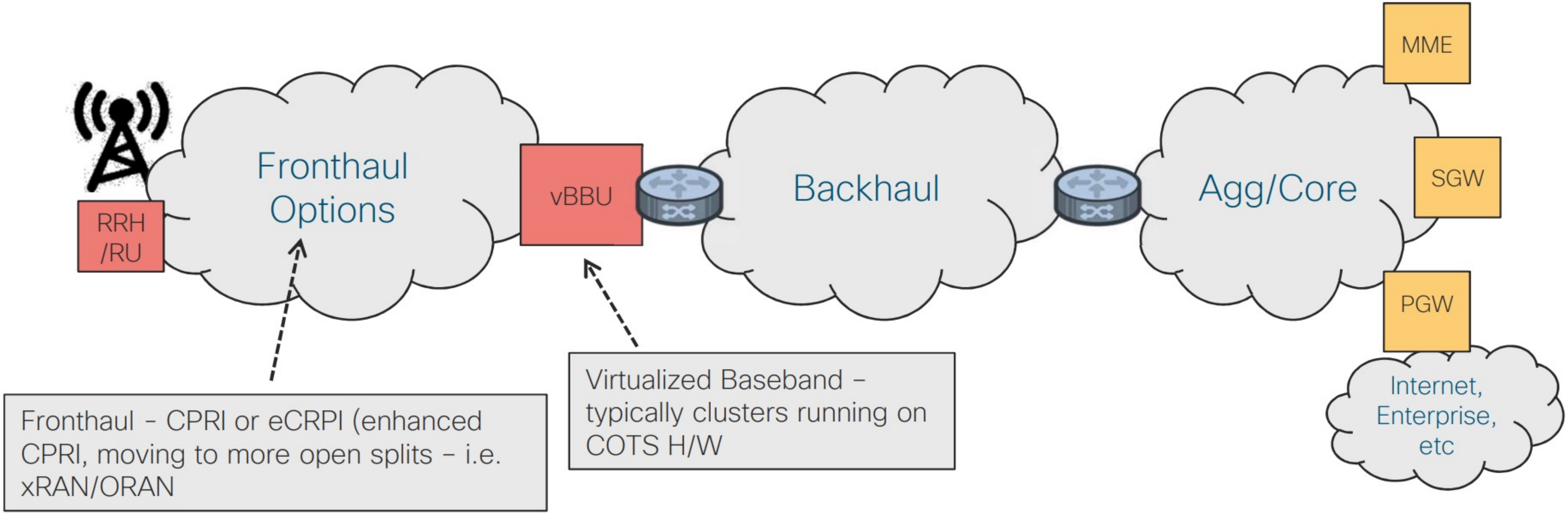
Centralized RAN

Remote BBU – typically proprietary closed platform



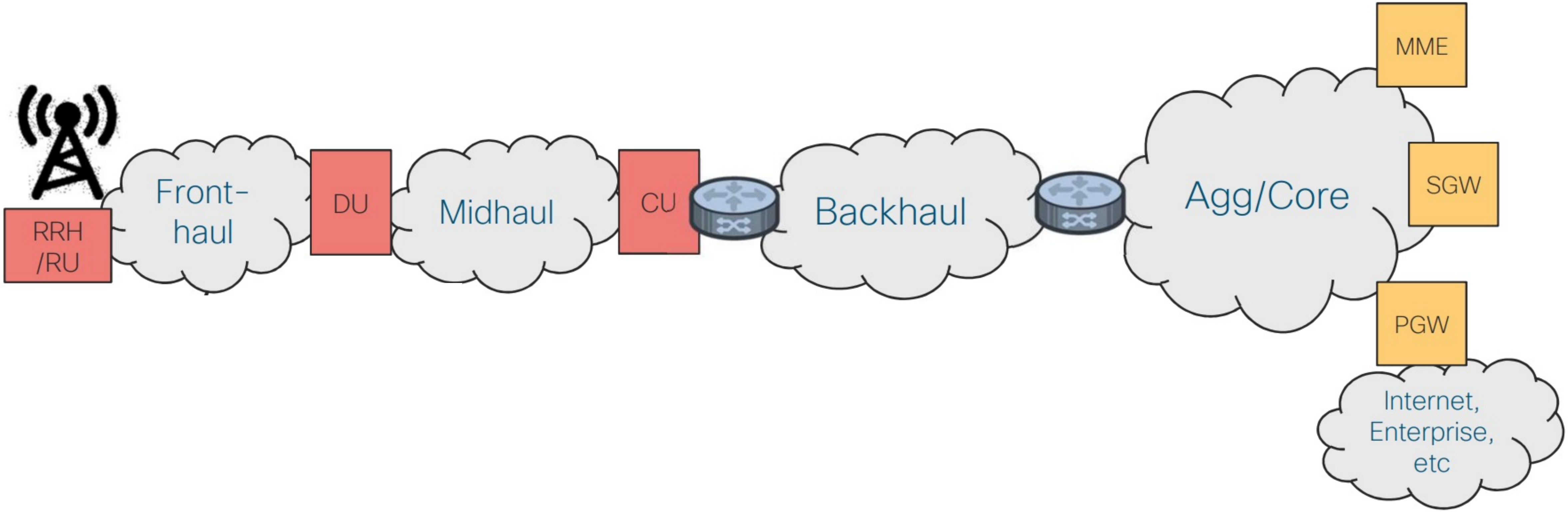
CPRI (Common Public Radio Interface) Fiber Fronthaul:
Constant Bit Rate – transmits even when no user traffic, no multiplexing
Highly inefficient – scales with number of antennas, not data rate
i.e. 150Mbps data = ~2.5Gbps CPRI traffic
Requires very low latency – 200μs
Optical transport; RAN vendor proprietary format

Cloud RAN



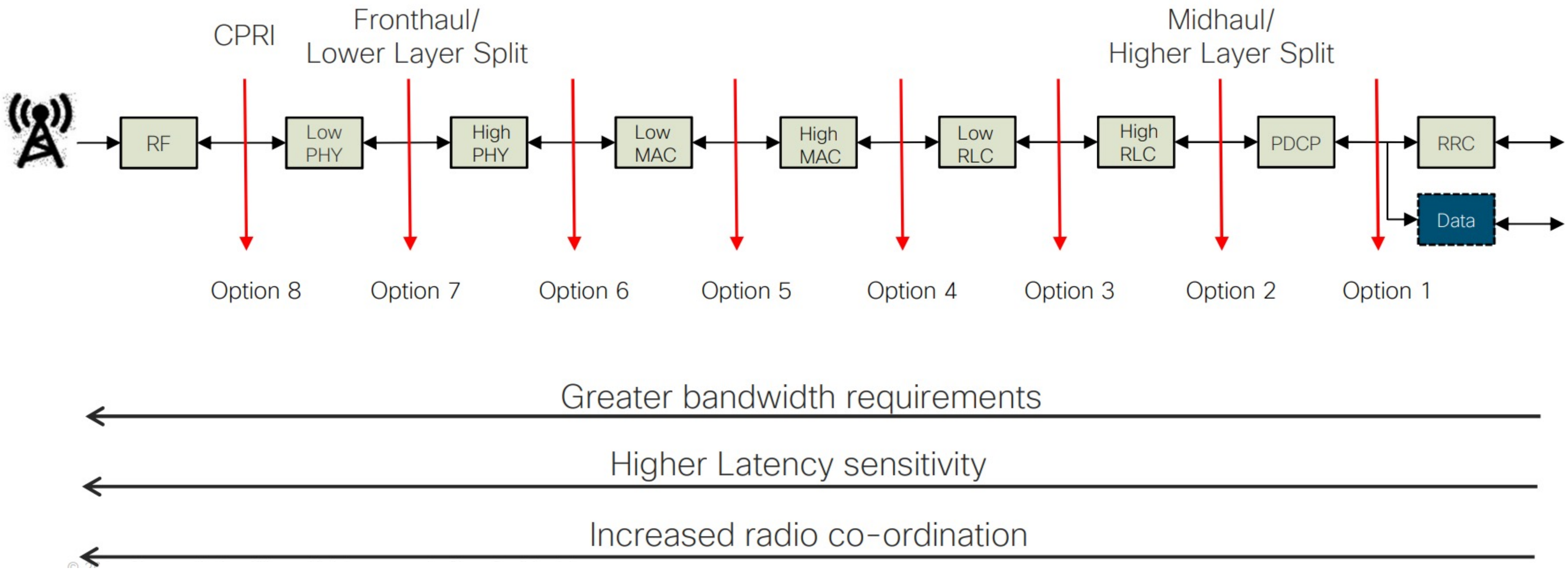
RRH
/RU
Fronthaul
Options
vBBU
Backhaul
Agg/Core
MME
SGW
PGW
Internet,
Enterprise,
etc
Fronthaul – CPRI or eCRPI (enhanced CPRI, moving to more open splits – i.e. xRAN/ORAN
Virtualized Baseband – typically clusters running on COTS H/W

Split vRAN

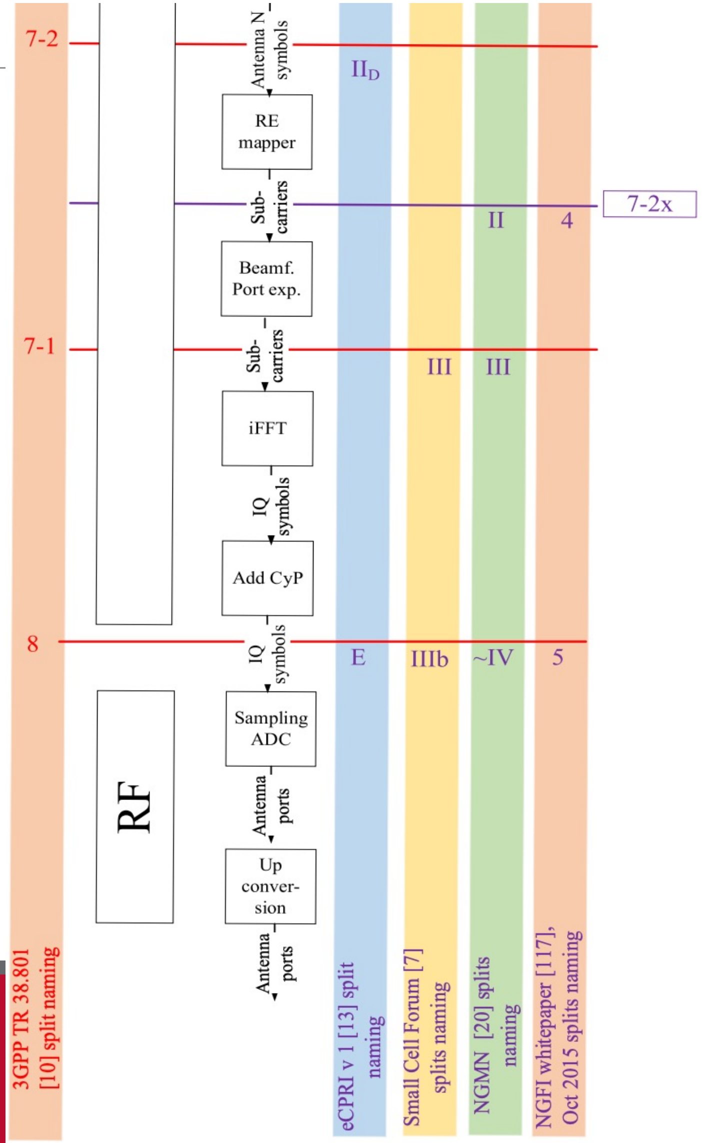


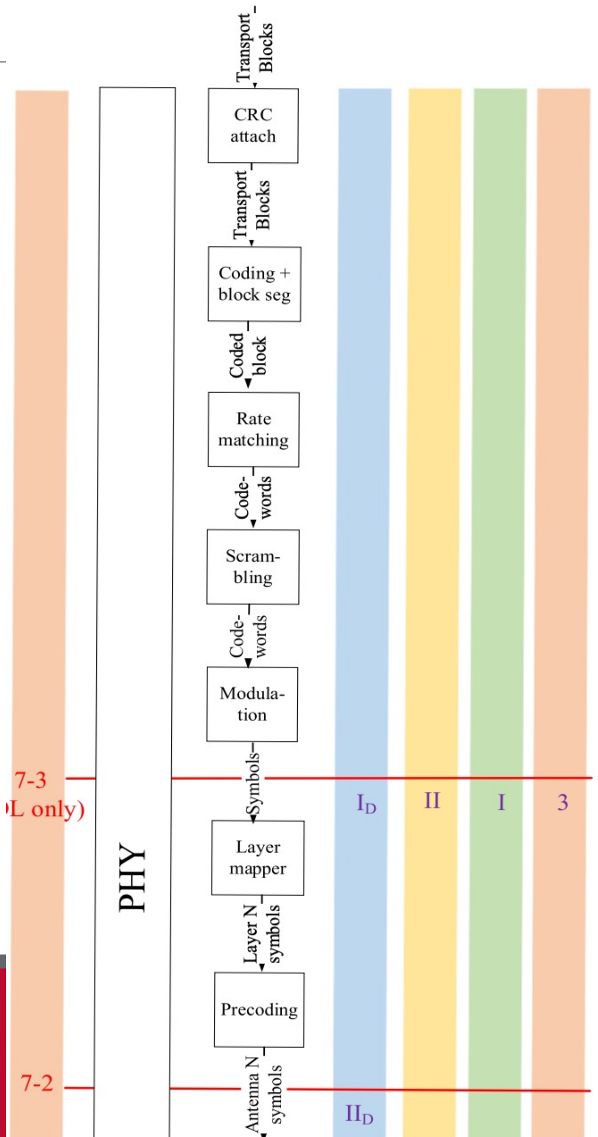
RRH
/RU
Front-
haul
DU
Midhaul
CU
Backhaul
Agg/Core
MME
SGW
PGW
Internet,
Enterprise,
etc

Where to split?



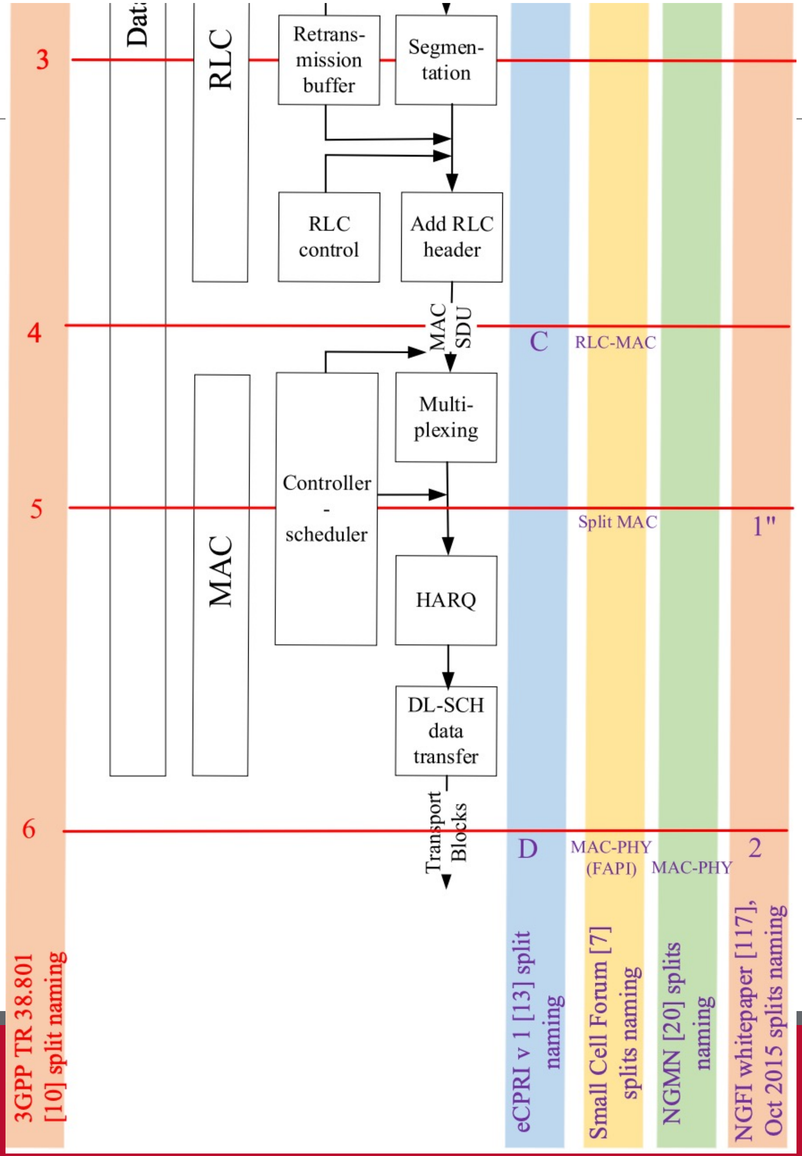
Split Options Detailed (7/8)

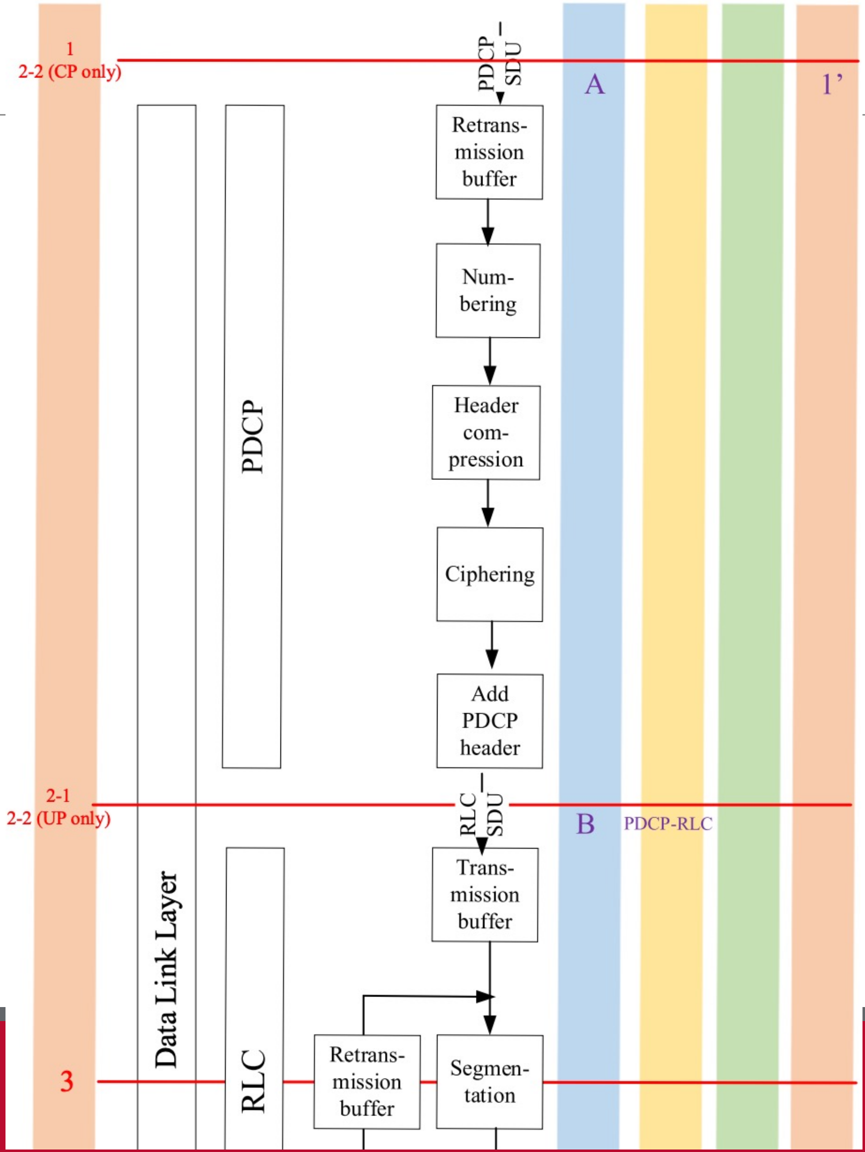




Pyndt Larsen, Line Maria; Checko, Aleksandra; Christiansen, Henrik Lehrmann, «A Survey of the Functional Splits Proposed for 5G Mobile Crosshaul Networks,» IEEE Communications Surveys and Tutorials, 2018, DOI: 10.1109/COMST.2018.2868805

Split Options Detailed (1/6)





Split Options

Option 1 (RRC/PDCP, 1A-like split): In this split option, RRC is in the central unit while PDCP, RLC, MAC, physical layer and RF are kept in the distributed unit. Thus the entire user plane is in the distributed unit.

Option 2 (PDCP/RLC split): Option 2 may be a base for an X2-like design due to similarity on U-plane but some functionality may be different e.g. C-plane since some new procedures may be needed. There are two possible variants available in this option.

- Option 2-1 Split U-plane only (3C like split): In this split option, RRC, PDCP are in the central unit. RLC, MAC, physical layer and RF are in the distributed unit.
- Option 2-2: In this split option, RRC, PDCP are in the central unit. RLC, MAC, physical layer and RF are in the distributed unit. In addition, this option can be achieved by separating the RRC and PDCP for the CP stack and the PDCP for the UP stack into different central entities.

Split Options

Option 3 (High RLC/Low RLC Split): In this option, two approaches are taken based on Real time/Non-Real time functions split which are as follows:

- Option 3-1 Split based on ARQ
- Low RLC may be composed of segmentation functions;
- High RLC may be composed of ARQ and other RLC functions;
- This option splits the RLC sublayer into High RLC and Low RLC sublayers such that for RLC Acknowledge Mode operation, all RLC functions may be performed at the High RLC sublayer residing in the central unit, while the segmentation may be performed at the Low RLC sublayer residing in the distributed unit. Here, High RLC segments RLC PDU based on the status reports while Low RLC segments RLC PDU into the available MAC PDU resources.
- Option 3-2 Split based on TX RLC and RX RLC
- Low RLC may be composed of transmitting TM RLC entity, transmitting UM RLC entity, a transmitting side of AM and the routing function of a receiving side of AM, which are related to downlink transmission.
- High RLC may be composed of receiving TM RLC entity, receiving UM RLC entity and a receiving side of AM except for the routing function and reception of RLC status reports, which are related to uplink transmission.
- NOTE: RLC transfers upper layer Protocol Data Units (PDUs) in one of three modes: Acknowledged Mode (AM), Unacknowledged Mode (UM) and Transparent Mode (TM)

Split Options

Option 4 (RLC-MAC split): In this split option, RRC, PDCP, and RLC are in the central unit. MAC, physical layer, and RF are in the distributed unit.

Option 5 (Intra MAC split) assumes the following distribution:

- RF, physical layer and lower part of the MAC layer (Low-MAC) are in the Distributed Unit
- Higher part of the MAC layer (High-MAC), RLC and PDCP are in the Central Unit
- Therefore, by splitting the MAC layer into 2 entities (e.g. High-MAC and Low-MAC), the services and functions provided by the MAC layer will be located in the Central Unit (CU), in the Distributed Unit (DU), or in both. An example of this kind distribution given below.
- In High-MAC sublayer the centralized scheduling in the High-MAC sublayer will be in charge of the control of multiple Low-MAC sublayers. It takes high-level centralized scheduling decision. The inter-cell interference coordination in the High-MAC sublayer will be in charge of interference coordination methods such as JP/CS CoMP.
- In Low-MAC sublayer the time-critical functions in the Low-MAC sublayer include the functions with stringent delay requirements (e.g. HARQ) or the functions where performance is proportional to latency (e.g. radio channel and signal measurements from PHY, random access control). It reduces the delay requirements on the fronthaul interface. Radio specific functions in the Low-MAC sublayer can for perform scheduling-related information processing and be reporting.

Split Options

Option 6 (MAC-PHY split): The MAC and upper layers are in the central unit (CU). PHY layer and RF are in the DU. The interface between the CU and DUs carries data, configuration, and scheduling-related information (e.g. MCS, Layer Mapping, Beamforming, Antenna Configuration, resource block allocation, etc.) and measurements.

Option 7 (Intra PHY split): Multiple realizations of this option are possible, including asymmetrical options which allow obtaining benefits of different sub-options for UL and DL independently.

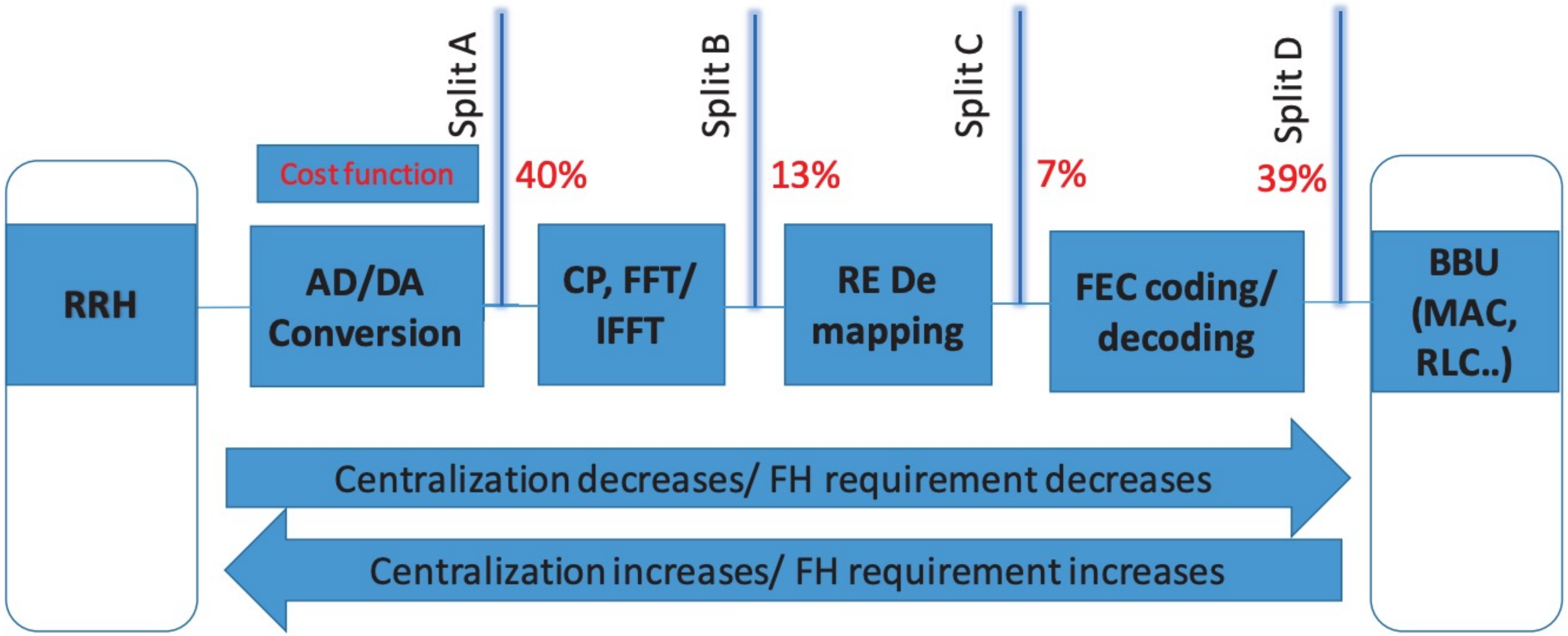
- This option requires some kind of compression technique to reduce transport bandwidth requirements between the DU and CU.
- In the UL, FFT, and CP removal reside in the DU and for the two sub-variants, 7-1 and 7-2 are described below. Remaining functions reside in the CU.
- In the downlink, iFFT and CP addition reside in the DU and the rest of the PHY resides in the CU.

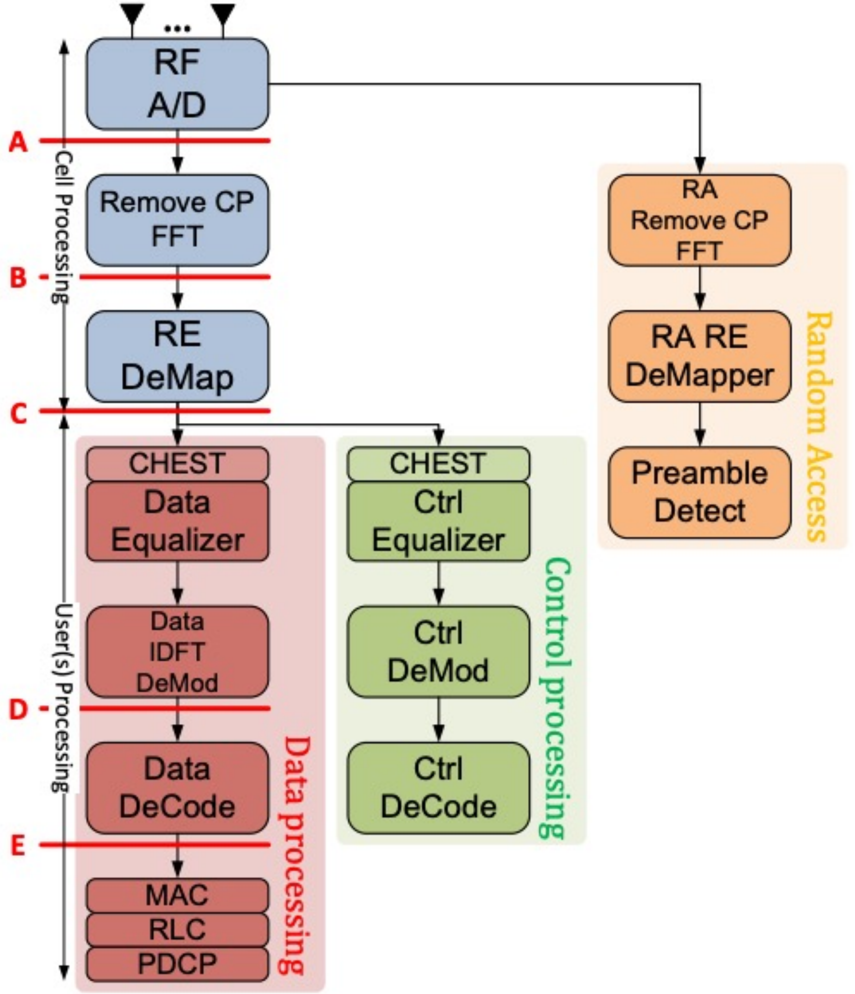
Split Options

- Option 7-1 In this option the UL, FFT, CP removal and possibly PRACH filtering functions reside in the DU, the rest of PHY functions reside in the CU. In the DL, iFFT and CP addition functions reside in the DU, the rest of PHY functions reside in the CU.
- Option 7-2 In this option the UL, FFT, CP removal, resource de-mapping and possibly pre-filtering functions reside in the DU, the rest of PHY functions reside in the CU. In the DL, iFFT, CP addition, resource mapping and precoding functions reside in the DU, the rest of PHY functions reside in the CU.
- Option 7-3 (Only for DL): Only the encoder resides in the CU, and the rest of PHY functions reside in the DU.

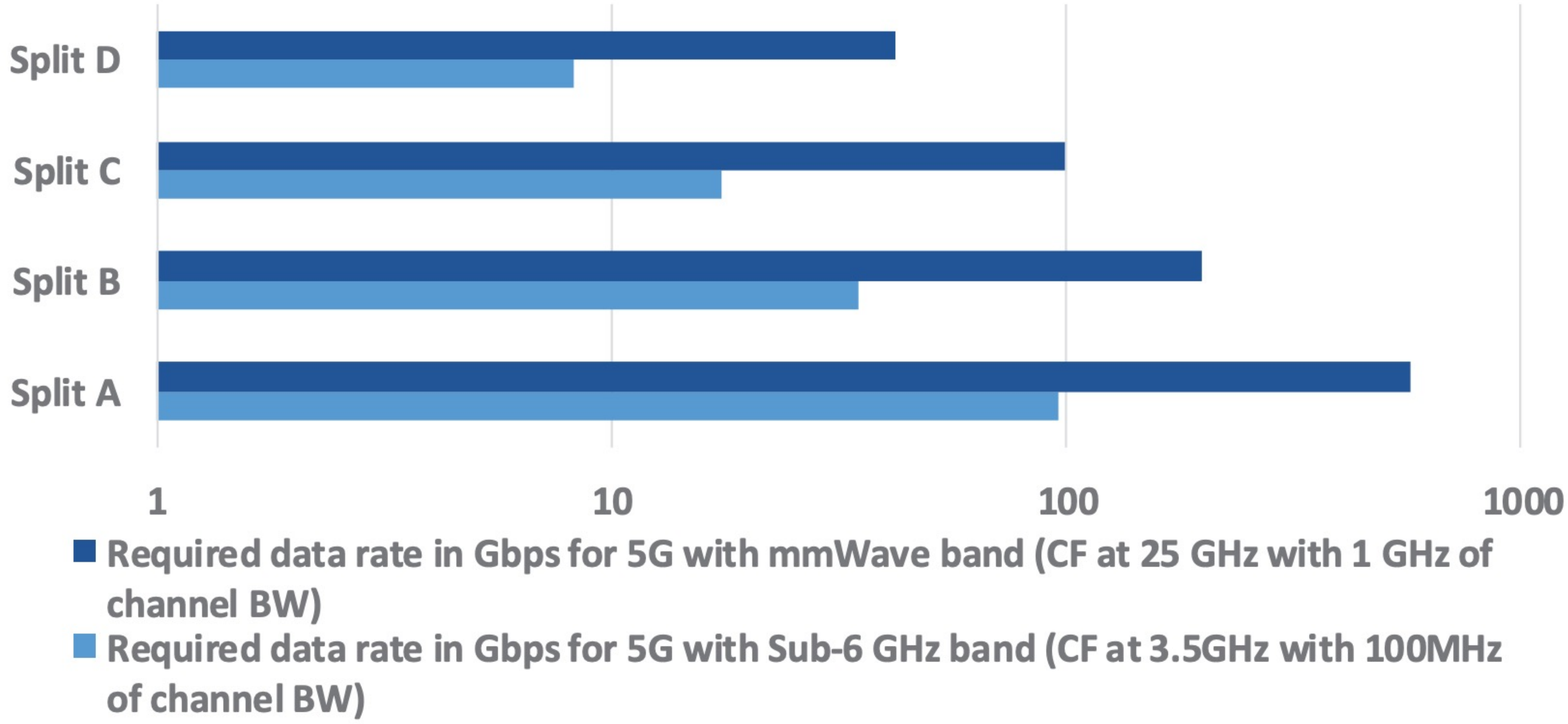
Option 8 (PHY-RF split): This option allows to separate the RF and the PHY layer. This split permit centralization of processes at all protocol layer levels, resulting in very tight coordination of the RAN. This allows efficient support of functions such as CoMP, MIMO, load balancing, mobility.

RRH/BBU Splitting



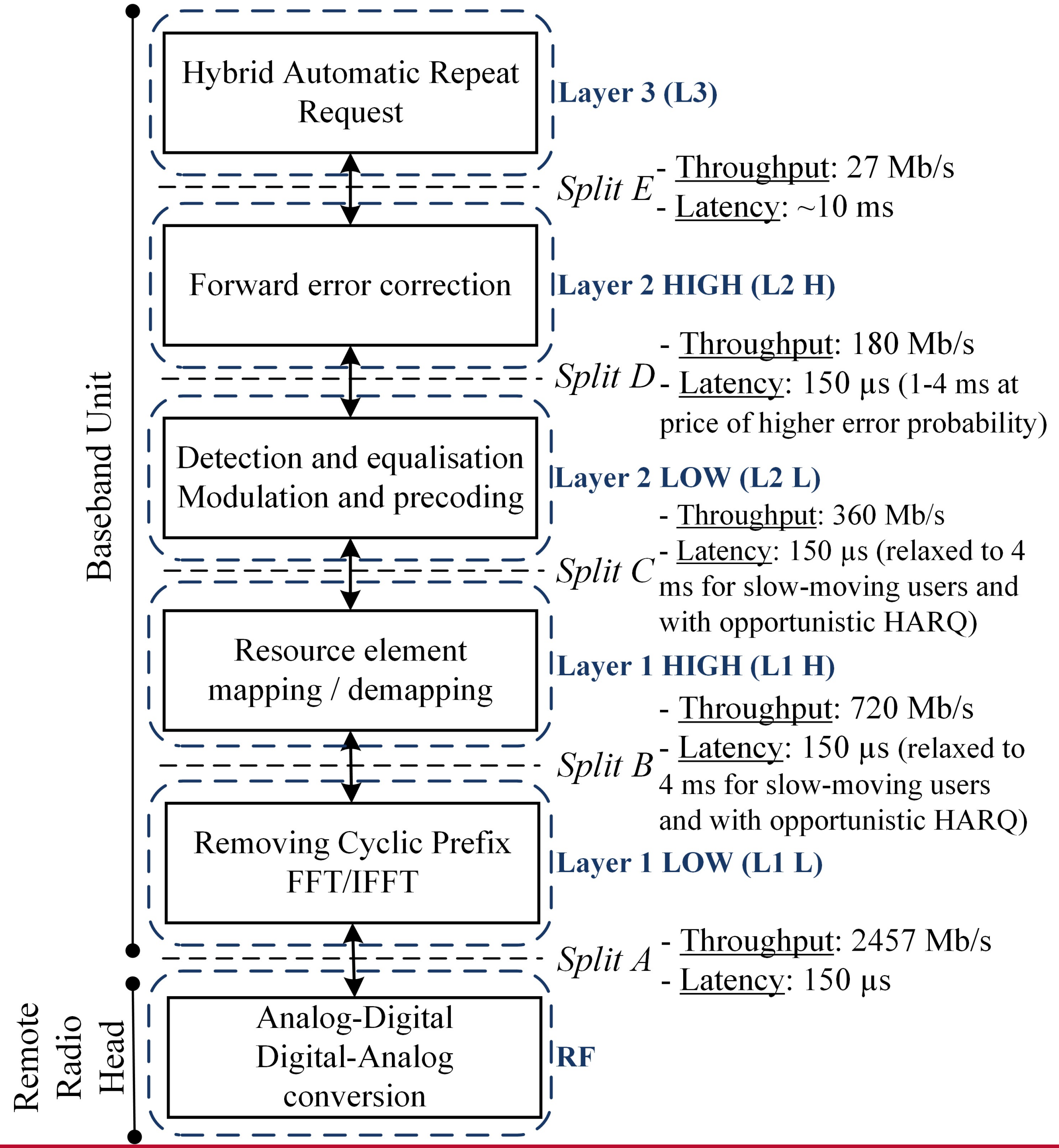


RRH/BBU Split on FrontHaul

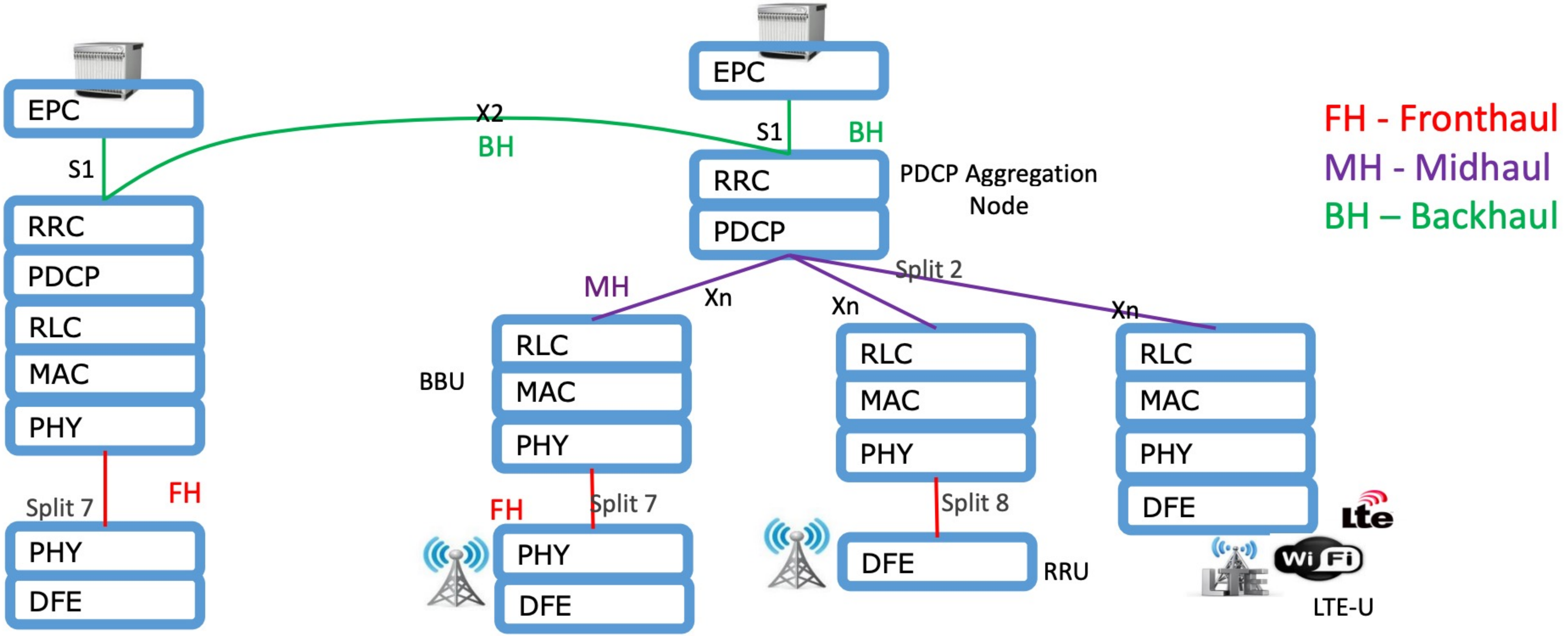


R.I. Rony, «Optimization of 5G Fronthaul based on Functional Splitting at PHY Layer,» IEEE Globecom.

RRH/BBU Split: Requirements



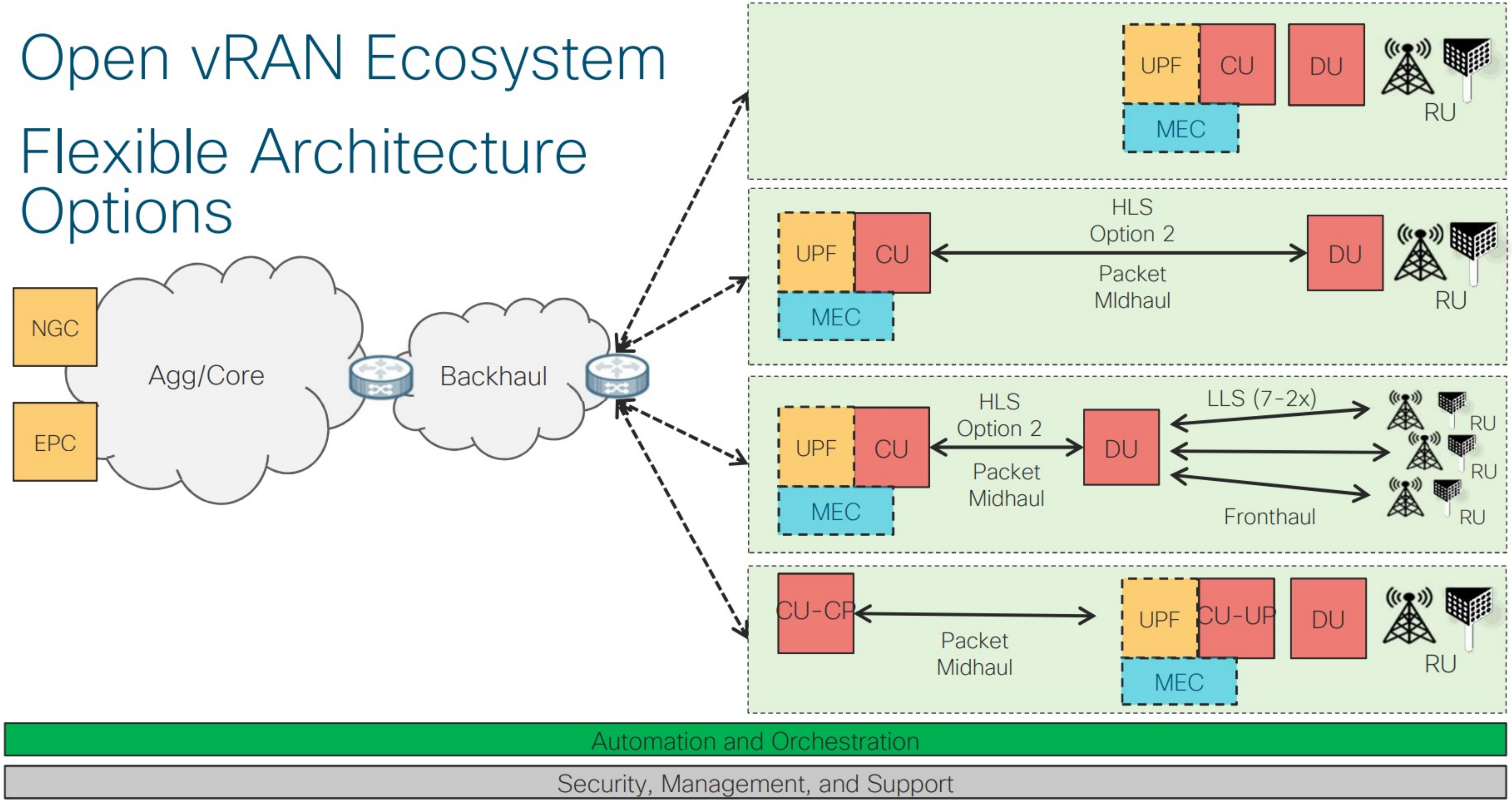
Deployment Examples



Example: Open vRAN

Open vRAN Ecosystem

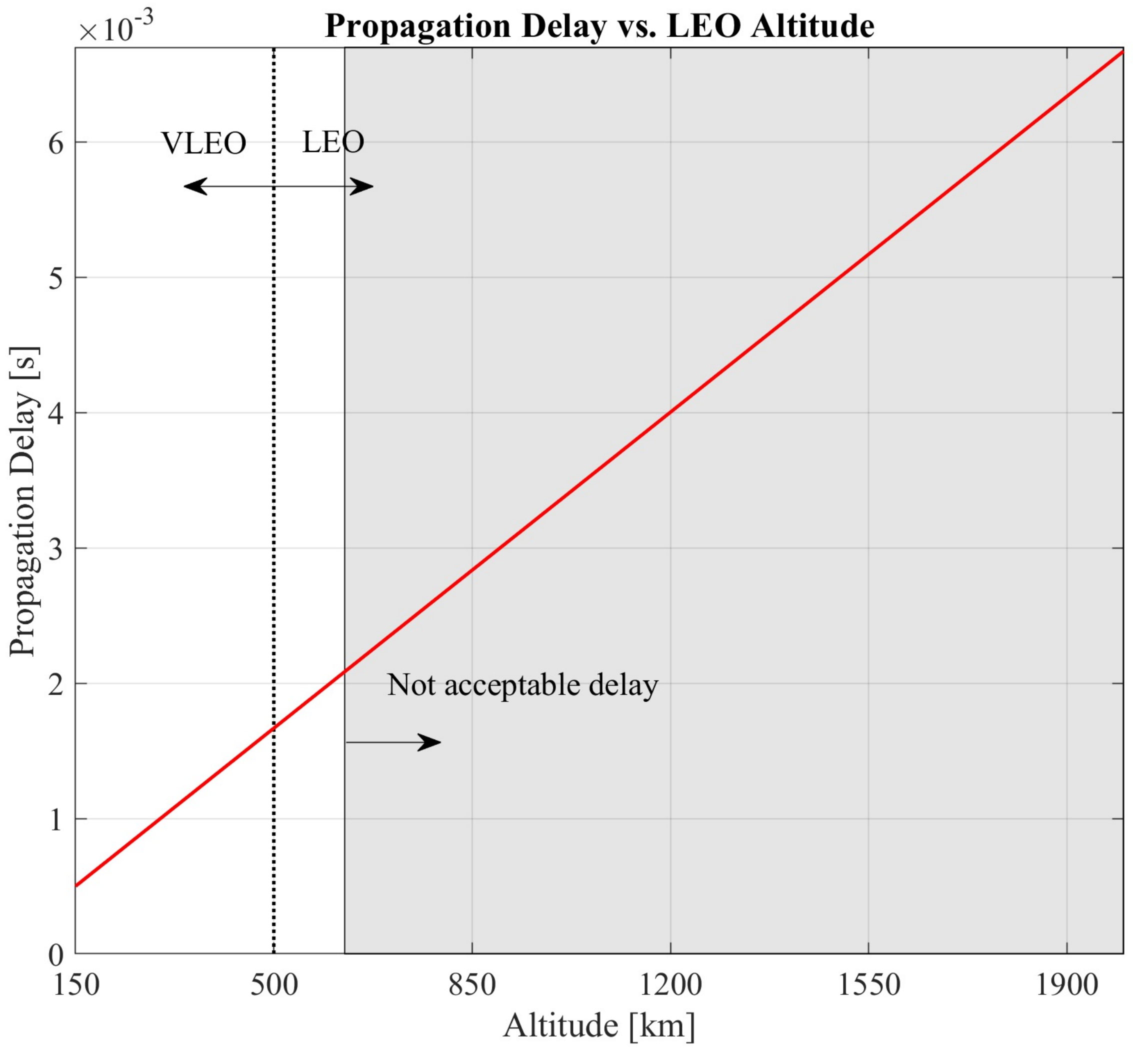
Flexible Architecture Options



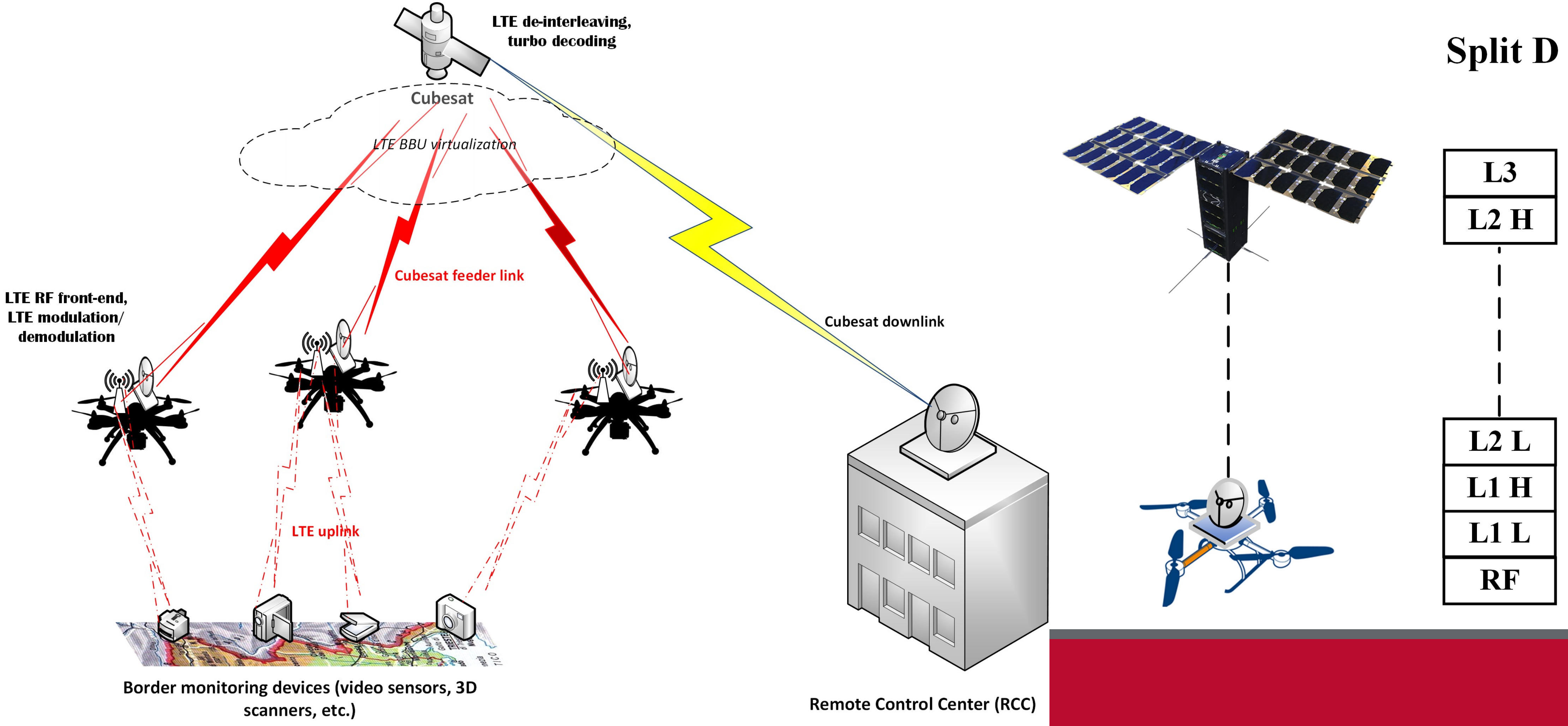
Example: Moving the BBU on satellites

Only **VLEO CubeSat orbits** can fulfill the requirements in terms of **BBU-RRH delay**.

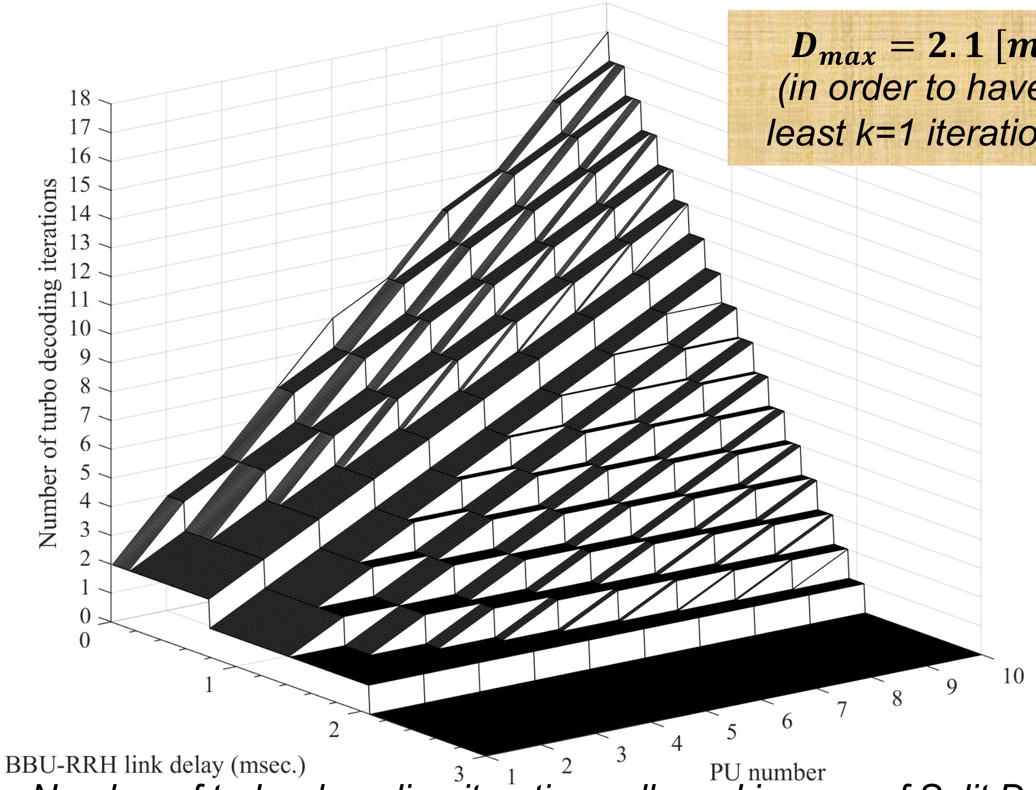
See: S. Bonafini, R. Bassoli, F. Granelli, F. Fitzek, C. Sacchi, “Virtual Baseband Unit Splitting Exploiting Small Satellite Platforms,”IEEE Aerospace Conference 2020



Example: BBUs on picosatellites



Example: BBUs on picosatellites



$\boldsymbol{D_{max} = 2.1\ [ms]}$
(in order to have at least k=1 iterations)

Number of turbo decoding iterations allowed in case of Split D of virtual BBU.

Turbo decoding iterations (k_max) that can be completed within a delay budget ϕ:

$$k_{max} = \max\left\{0, \left\lfloor \frac{pO(\phi - J - D - T_{proc})}{LF} \right\rfloor\right\}$$

- p is the computational power of a single core processor in Giga operations per second (1.2 GOPS);
- O is number of core processors installed inside the remote BBU;
- ϕ is the delay budget (3ms for LTE);
- J is the time required for processing other wireless functions (0.9 ms);
- D is the CubeSat feeder link delay;
- L is turbo−coded block length in bit (6144 bit);
- F is the number of elementary operations required per decoding iteration (200);
- T_proc is the processing time required by the detection of the LTE turbo−coded block coming from the RRH: $L/R\_b\text{^}CRAN$ with $R\_b\text{^}CRAN$=181 $[Mbit/s]$

Example: BBUs on pico-satellites

Performance of vitualized iterative turbo decoding vs. CubeSat flight time: 16-QAM modulation